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OKLAHOMA CITY TASTE AND ODOR STUDY.
A PRELIMINARY STUDY OF THE TASTE AND
ODOR PROBLEMS IN THE OKLAHOMA CITY
WATER SUPPLY

Clarence M. Tarzwell

Environmental Health Center
Cincinnati, Ohio

June 1950

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Cincinnati, Ohio
June, 1950

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A Preliminary Study of the Taste and Odor Problems
in the Oklahoma City Water Supply

NATIONAL TECHNICAL
INFORMATION SERVICE

By

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Prepared by the Environmental Health Center,
Public Health Service, at the request of and
in cooperation with the District Engineers,
Tulsa District, Corps of Engineers.

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ABSTRACT

The domestic water supply of Oklahoma City is secured from two storage reservoirs which are filled by water taken from the North Canadian River. The oldest of these reservoirs, Overholser, was put into operation in 1919 while the first water was taken from the other, Lake Hefner, in December, 1946. During the past several years serious taste and odor problems have not occurred in Lake Overholser, but shortly after Hefner was put in operation tastes and odors developed and became serious at periodic intervals. In September, October, and November, 1949, tastes and serious odors developed which were very difficult to control. Due to the fact that algae populations averaged larger in Lake Overholser where no taste and odors have developed, that algae populations in Hefner were never of a magnitude which are considered sufficient for the production of tastes and odors and that tastes and odors occurred during periods when algae populations were low, it is concluded that the tastes and odors in Lake Hefner may not be due to algae growths. Streptomyces, a genus of Actinomycetales, was isolated from the waters of Lake Hefner and grown on culture media with the production of odors similar to those noted in the lake waters. It is believed that these organisms may be responsible for the tastes and odors and have grown on organic materials which were inundated by the impoundment of the water in Lake Hefner. Oklahoma City authorities were apprehensive, therefore, that such tastes and odors may also develop in the new Canton Reservoir on the North Canadian River. If this occurred, it is feared that their source of water for both reservoirs would present taste and odor problems. Taste and odor problems which have occurred to date in Lake Hefner cannot be ascribed to Canton Reservoir. However, an examination of Canton Reservoir indicates that extensive shallow areas, rich in vegetation, will probably develop when the reservoir level is raised to the initial irrigation pool elevation. At present, so little is known concerning the ecology and life history of Actinomycetales that it cannot definitely be predicted whether or not they will grow in these areas and produce tastes and odors which will be carried downstream to the Oklahoma City water supplies. Intensive studies are urgently needed on the ecology, life history and by-products formed by these organisms in order that they may be biologically or chemically controlled or their by-products efficiently handled in water purification plants.

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A PRELIMINARY STUDY OF THE TASTE AND ODOR PROBLEM
IN THE OKLAHOMA CITY WATER SUPPLY

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Introduction

During September, October and November, 1949, the Water Department of Oklahoma City had a very serious taste and odor problem in one of their two storage reservoirs, Lake Hefner. The Lake Hefner plant was placed in operation in December, 1946. During the first two years of operation, the threshold odor of the raw water taken from Lake Hefner averaged higher than that taken from the older reservoir, Overholser, and reached a maximum of 14 in June 1947, and in February and March, 1948. However, after a low threshold odor during the first 9 months of 1949, there was a sudden increase in odor in September, maximum threshold odors being 40 in September, 90 in October and 40 in November. This odor was very persistent, difficult and costly to remove. Normally, the cost of chemicals for treating the Lake Hefner water has averaged about \$12.00 per million gallons of water varying from a low of \$7.77 to a high of \$19.14. However, during the three above mentioned months of high threshold odors, costs were \$46.50, \$52.36 and \$27.00 per million gallons of water. This represents a considerable cost to the city and if it becomes an annual occurrence will necessitate a considerable capital outlay for additional plant facilities.

During the month of October, 1949, an average of 496 pounds of activated carbon were used per million gallons of water for the adsorption of odors and tastes. Under normal rates of application, some of this carbon passed through the filters and it was necessary to drastically

reduce the rate of application to the filters. A four million dollar addition is now being planned for the Lake Hefner plant, half the cost of which is made necessary by this taste and odor problem which has produced a need for additional filters. The taste and odor problem is therefore of real importance to Oklahoma City and is the outstanding problem of the water plant operator.

Because these problems have arisen in the new storage reservoir, Hefner, and all water supplies are obtained from the North Canadian River, the Oklahoma City officials are apprehensive of the possible effects of the recently completed Canton Reservoir on their water supply. On October 17, 1949, Mr. H. B. Cunningham, Superintendent of the Oklahoma City Water Department, wrote to Colonel Edward G. Daly, District Engineer of the Tulsa District Corps of Engineers, requesting assistance from the Corps of Engineers in meeting this problem. Mr. Cunningham pointed out that the water in Canton reservoir had been largely impounded during the past year with the resultant flooding of an area which had a dense covering of grasses, weeds and underbrush which may result in the production of tastes and odors. He suggested that the Public Health Service be requested to make studies on Canton Reservoir of the possibilities of the production of tastes and odors and the possible effects that the water released from Canton Reservoir will have on the water supply reservoirs of Oklahoma City.

The Corps of Engineers called the situation to the attention of the Environmental Health Center at Cincinnati, and a preliminary investigation was planned. The purpose of this investigation was to study ecological conditions in Canton Reservoir and to examine the situation at Oklahoma

City in order that the problem could be more adequately defined. Detailed arrangements for conferences with the various agencies concerned were made by the Southwest-Lower Mississippi Drainage Basin Office. Two representatives of that office accompanied the biologist from the Environmental Health Center on the reconnaissance trip.

The office of the Corps of Engineers at Tulsa was visited for the purpose of securing physical and operational data on Canton Reservoir. Charts showing inflow, outflow, pool elevation, storage volume and available flood control storage for the period May 1948 to February 1950 were secured, as well as information on the reservoir, maps of the area and maps of the North Canadian River from Canton Reservoir to Oklahoma City. The general character of the reservoir and its operation were discussed with Mr. C. E. Solomon, Chief, Reservoir Development Branch and Mr. F. O. Swiggart, Hydrology Section, who were very cooperative and furnished much valuable background information.

Representatives of the Oklahoma State Health Department, the Oklahoma City Water Department, U. S. Geological Survey, Corps of Engineers, U.S. Fish and Wildlife Service, Oklahoma Game and Fish Department and the Public Health Service met in the offices of the State Health Department to discuss the taste and odor problem. Past difficulties and methods used in attempting to overcome them were described. It was brought out that taste and odor problems of this type are not uncommon in the southwest and that it was not purely an Oklahoma City problem. About a hundred municipalities in Oklahoma depend on surface waters for their domestic supplies and several of them have experienced similar taste and odor problems.

problems. Similar problems have arisen in Texas, especially at Dallas. It was brought out that these taste and odor problems differed from those which have ordinarily been attributed to algae and that investigations are needed to determine the causative agent or agents and the method for their control. Those facing these problems are very desirous that such investigations be undertaken as soon as possible.

The Oklahoma City water supply reservoirs and plants were examined and data collected on their physical characteristics, their mode of operation, the chemical content of the water, turbidities and their general ecology.

Lake Overholser, Operation and Ecology -

Lake Overholser, the older of the two water supply reservoirs was put into operation in 1919. It now has a capacity of 17,000 acre feet, an area of 1700 acres and an average depth of 10 feet. A considerable portion of the reservoir is fairly shallow and wind action stirs up bottom materials keeping the water muddy. The average turbidity is over 100 but the range is very wide, varying from 10 to 3,000 during the past three years (Table 1). The water is generally well mixed throughout the reservoir during the spring because of extensive wind action, but stratification sometimes occurs during the summer months. Fish are fairly abundant in the reservoir and fishing is permitted.

Water is taken into the reservoir from the North Canadian River over a "roll-over". The main stream is bypassed in a canal, the level of which can be regulated. When possible, water is taken into the reservoir during flood periods when the mineral content and hardness of the water are

low. Analyses are made of the water coming down the river and the water for the reservoir is carefully selected. If an abundance of water softer than that in the reservoir is available, the soft water is let in at the upper end and the harder water in the reservoir is let out at the lower end. This practice results in the water in the reservoir being considerably softer than that of the river during normal flow.

No data were obtained on taste and odor problems which may have been encountered with Lake Overholser water shortly after impoundment. In recent years, however, there have been no serious problems, the threshold odor of the raw water has varied from 2 to 6 averaging about 3. Turbidity, alkalinity, threshold odor, total hardness, pH, dissolved oxygen, temperature and cost of treatment for Lake Overholser water for the period April, 1945 to February, 1950, are summarized by months in Table I. Dissolved oxygen becomes quite low during the summer months of June, July, August and September, usually reaching a minimum of 2 to 3 p.p.m. This is approaching the critical stage for survival of fishes. Lake Overholser possesses considerable aquatic vegetation and is considered to be a fairly productive body of water.

Lake Hefner, Operation and Ecology -

Hefner Reservoir, the second of the Oklahoma City water storage reservoirs, is located 10 miles northwest of the city. It is formed by a 5 mile dam across the upper valley of Bluff Creek, a tributary of the Cimarron River. Water for Lake Hefner is taken from the North Canadian River just north of Lake Overholser, through a series of five mechanically operated gates, and is lead over the divide and to the lake through a $4\frac{1}{2}$ mile channel which has a capacity of 1500 cfs. The lake has a natural drainage area of about 10 square miles which is zoned to prevent pollution.

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LAKE SUPERIOR
Water Quality and Treatment

Date	Turbidity of Raw Water			Total Alkalinity of Raw Water			Threshold Color of Raw Water			Total Hardness of Raw Water		
	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.
Apr. 45	230	1000	80	151	173	130				201	251	177
May 45	98	200	80	143	174	137				197	241	177
June 45	105	180	80	154	170	145				206	251	177
July 45	87	100	80	151	177	130				197	241	177
Aug. 45	88	150	45	170	174	130				191	230	150
Sept. 45	80	200	40	167	173	138				202	238	152
Oct. 45	105	240	50	161	173	136				190	230	155
Nov. 45	85	85	45	161	170	150				214	230	155
Dec. 45	40	50	10	177	185	164				211	230	155
Jan. 46	24	30	10	184	183	173				211	230	155
Feb. 46	157	200	30	184	190	180				211	230	155
Mar. 46	153	350	100	195	200	185				208	230	155
Apr. 46	143	200	85	201	206	191				218	230	155
May 46	185	185	180	190	195	179				217	231	155
June 46	140	140	140	167	167	152				211	230	155
July 46	140	140	140	132	150	127				210	230	155
Aug. 46	103	120	100	137	142	132				210	216	155
Sept. 46	100	100	100	141	148	140				211	212	155
Oct. 46	142	500	100	144	140	145				214	214	155
Nov. 46	140	140	140	163	170	160				214	214	155
Dec. 46	140	140	140	164	170	158				214	214	155
Jan. 47	157	800	100	166	175	160				214	214	155
Feb. 47	214	500	100	174	190	165				214	214	155
Mar. 47	100	100	100	188	200	180				201	229	172
Apr. 47	472	1200	100	163	188	138				208	231	170
May 47	251	600	100	138	150	123				215	228	150
June 47	185	200	150	177	141	130	6	6	6	217	200	151
July 47	131	150	100	132	140	128	5	5	5	217	202	151
Aug. 47	97	100	80	138	143	131	5	5	5	210	211	155
Sept. 47	85	85	85	141	142	139	5	5	5	210	227	159
Oct. 47	85	85	85	141	160	148	3	3	3	210	215	153
Nov. 47	85	85	85	166	172	158	3	3	3	216	216	158
Dec. 47	85	85	85	169	185	165	3	3	3	216	216	158
Jan. 48	85	100	85	173	183	170	3	3	3	216	216	158
Feb. 48	98	145	85	173	188	157	3	3	3	215	216	159
Mar. 48	162	2000	85	174	188	155	3	3	3	215	216	159
Apr. 48	88	150	85	179	185	148	3	3	3	215	216	159
May 48	85	85	85	179	180	135	3	3	3	215	216	159
June 48	85	85	85	173	183	115	3	3	3	215	216	159
July 48	185	185	185	173	173	118	3	3	3	191	205	174
Aug. 48	100	100	100	140	145	135	3	3	3	210	219	200
Sept. 48	100	100	100	144	152	145	3	3	3	217	226	205
Oct. 48	100	100	100	154	159	152	3	3	3	222	236	195
Nov. 48	100	100	100	164	168	160	3	3	3	224	241	220
Dec. 48	100	100	100	178	177	168	3	3	3	232	257	248
Jan. 49	100	100	100	175	177	170	3	3	3	234	257	250
Feb. 49	100	100	100	165	182	150	3	3	3	239	262	212
Mar. 49	100	100	100	139	168	152	3	3	3	235	245	212
Apr. 49	100	100	100	168	170	165	3	3	3	248	260	228
May 49	253	3000	100	149	170	110	3	3	3	230	276	172
June 49	100	100	100	123	135	115	3	3	3	175	191	164
July 49	100	100	100	146	145	135	3	3	3	176	200	172
Aug. 49	100	100	100	141	150	140	3	3	3	192	200	154
Sept. 49	100	100	100	146	152	140	3	3	3	204	210	154
Oct. 49	100	100	100	151	158	145	3	3	3	204	210	154
Nov. 49	100	100	100	151	160	145	2.6	2.6	2.6	215	215	154
Dec. 49	100	100	100	168	170	162	3	3	3	215	215	154
Jan. 50	100	100	100	170	174	165	2	2	2	215	215	154
Feb. 50	100	100	100	174	178	172	2	2	2	215	215	154

TABLE 1
Continued

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LAKE OVERHOLSER
Water Quality and Treatment

Date	Total Sediment Load Tons	Total Sediment Load Tons	Lake Level Feet	Temperature			Dissolved Oxygen			Hardness of Raw Water		
				Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.
Apr. 45	7.35	27.5		50	63	54				3.6	9.0	1.3
May 45	8.28	27.1		50	75	50				3.6	9.0	1.3
June 45	9.16	30.4		74	79	72				3.4	8.6	3.1
July 45	8.87	33.1		72	81	77				3.0	8.4	7.5
Aug. 45	9.55	30.6		80	82	78				3.05	8.2	7.5
Sept. 45	9.84	33.5		73	80	62				3.2	8.4	3.0
Oct. 45	9.44	24.1		62	66	57				3.1	8.6	3.1
Nov. 45	9.26	21.0		51	53	47						
Dec. 45	10.54	18.1		41.7	50	35	11.3	12.2	10.2			
Jan. 46	11.28	17.9		42	48	38	10.5	11.5	9.5	3.3	8.6	3.4
Feb. 46	12.84	19.54		46.6	52	41	9.5	11.2	7.7	3.5	8.6	3.4
Mar. 46	13.32	24.2		54	61	49	7.6	9.3	6.8	3.5	8.6	3.4
Apr. 46	14.10	30.1		54.5	57	52	9.9	7.8	6.4	3.6	8.6	3.4
May 46	14.90	33.7		58	72	52	6.7	7.6	5.7	3.64	8.9	3.6
June 46	13.21	31.5		75	80	69	7.6	9.6	4.3	3.7	8.9	3.4
July 46	10.28	37.3		81	83	78	7.0	7.7	3.0	3.7	8.7	3.2
Aug. 46	9.15	38.5		82	84	74	4.3	6.2	2.6	3.6	8.7	3.2
Sept. 46	7.69	37.9		74	78	69	4.5	9.0	2.0	3.7	8.8	3.4
Oct. 46	10.06	37.4		65	68	61	6.9	7.6	5.0	3.7	8.9	3.4
Nov. 46	12.30	32.1		56	66	50	3.5	5.8	6.4	3.7	8.9	3.6
Dec. 46	11.82	34.7		56	61	46	12.1	11.4	9.0	3.2	8.8	3.2
Jan. 47	11.30	30.4		44	50	39	12.5	13.8	10.6	3.2	8.4	3.0
Feb. 47	10.58	30.3		44	50	39	12.1	13.2	10.8	3.3	8.4	3.0
Mar. 47	11.29	19.1		49	59	42	10.7	12.4	9.0	2.3	8.0	3.0
Apr. 47	15.22	13.48		59	64	52				3.0	8.3	7.5
May 47	7.34	19.3		67	69	62	6.5	8.0	4.8	7.9	8.3	7.1
June 47	7.50	23.9		74	79	66	6.1	7.3	4.4	3.4	8.3	7.3
July 47	8.14	14.5		79	82	76	4.7	6.2	3.3	3.2	8.4	7.0
Aug. 47	7.73	17.1		81	82	80	4.1	5.2	3.3	3.2	8.4	7.0
Sept. 47	7.83			79	83	73	5.5	5.7	2.4	3.4	8.4	7.0
Oct. 47	9.11	30.4		73	76	69	6.3	7.7	5.6	3.2	8.4	7.0
Nov. 47	9.36	25.2		58	69	53	8.4	10	7.6	3.4	8.5	7.0
Dec. 47	8.29	6.75		46	50	44	10.5	13.2	7.0	3.1	8.4	7.0
Jan. 48	16.78	31.6		38	43	34	9.8	14.2	9.0	3.3	8.4	7.0
Feb. 48	13.90	28.8		38	46	34	11.1	12.4	9.5	3.3	8.4	7.0
Mar. 48	11.50	38.3		56	66	54	9.1	12.4	7.2	3.5	8.6	7.5
Apr. 48	12.12	31.1		62	67	57	8.6	8.3	5.5	3.5	8.6	7.5
May 48	13.71			65	73	60	5.9	7.2	3.5	3.5	8.6	7.5
June 48	12.26	39.8		77	80	73	7.6	8.1	3.1	3.4	8.6	7.5
July 48	8.73	42.2		81	83	78	7.6	7.7	3.1	3.4	8.6	7.5
Aug. 48	8.05	32.1		82	83	80	4.1	4.5	3.1	3.0	8.6	7.5
Sept. 48	9.61	35.2		78	87	74	7.4	5.3	3.3	3.0	8.6	7.5
Oct. 48	10.01	30.8		66	74	60	6.4	7.4	3.4	3.0	8.6	7.5
Nov. 48	9.47	23.8		54	61	48	4.1	5.1	3.1	3.0	8.6	7.5
Dec. 48	12.85	13.7		46	50	40	7.2	9.2	4.0	3.4	8.4	7.0
Jan. 49	13.58	15.2		37	43	34	10.9	13.0	9.4	3.4	8.4	7.0
Feb. 49	11.12	18.8		37	43	34	10.9	13.0	10.4	3.4	8.4	7.0
Mar. 49	12.22	23.4		56	66	54	9.9	12.9	9.2	3.5	8.6	7.5
Apr. 49	12.73	21.1		62	67	57	8.6	8.3	5.5	3.5	8.6	7.5
May 49	12.12	24.6		65	73	60	5.9	7.2	3.5	3.5	8.6	7.5
June 49	8.73	42.2		81	83	78	7.6	8.1	3.1	3.4	8.6	7.5
July 49	8.05	32.1		82	83	80	4.1	4.5	3.1	3.0	8.6	7.5
Aug. 49	9.61	35.2		78	87	74	7.4	5.3	3.3	3.0	8.6	7.5
Sept. 49	10.01	30.8		66	74	60	6.4	7.4	3.4	3.0	8.6	7.5
Oct. 49	9.47	23.8		54	61	48	4.1	5.1	3.1	3.0	8.6	7.5
Nov. 49	12.82	21.3		37	43	34	10.9	13.0	9.4	3.4	8.4	7.0
Dec. 49	13.16	12.52		37	43	34	10.9	13.0	9.4	3.4	8.4	7.0
Jan. 50	12.10	14.4	2.2	41	51	39	10.2	11.6	10.0	3.6	8.7	3.7
Feb. 50	12.02	13.7		41	51	39	10.7	11.4	10.0	3.2	8.7	3.0

When full, at elevation 1200 feet, the reservoir has an area of 2662 acres, a storage capacity of 78,310 acre feet, and a maximum depth of 96 feet. In comparison to surface area, the volume of the reservoir is large and it contains no extensive shoal areas. The increase in surface area with each 5 foot increase in depth is given in Table 2.

TABLE 2
Area Flooded with Each Five Foot Increase
in Water Elevation in Lake Hefner

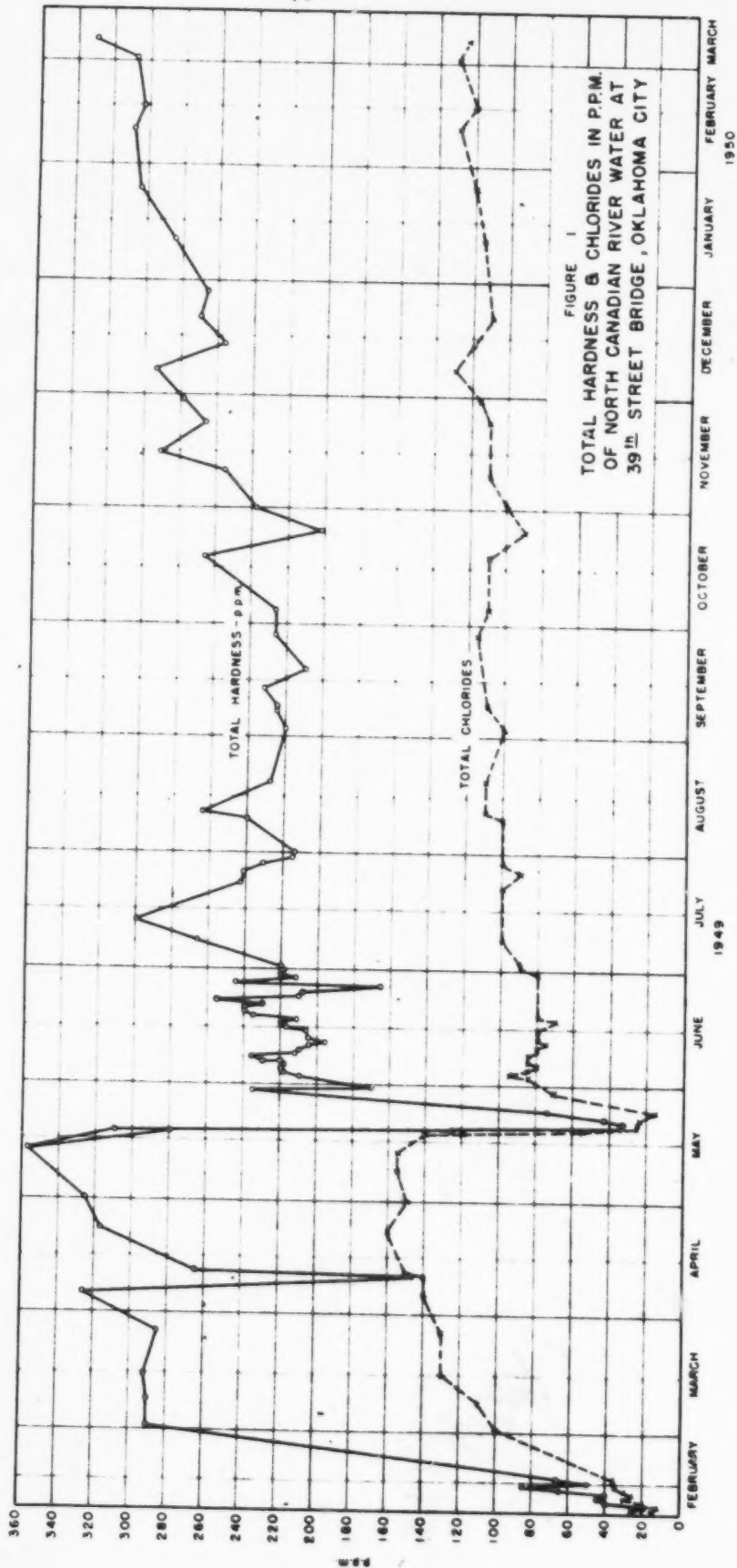
<u>Levels</u>	<u>Successive Increases in Surface Area</u>
1104	Bottom
1105 - 1110	8 acres
1110 - 1115	7 "
1115 - 1120	11 "
1120 - 1125	46 "
1125 - 1130	47 "
1130 - 1135	58 "
1135 - 1140	70 "
1140 - 1145	114 "
1145 - 1150	128 "
1150 - 1155	134 "
1155 - 1160	131 "
1160 - 1165	213 "
1165 - 1170	190 "
1170 - 1175	212 "
1175 - 1180	260 "
1180 - 1185	261 "
1185 - 1190	211 "
1190 - 1195	226 "
1195 - 1200	335 "

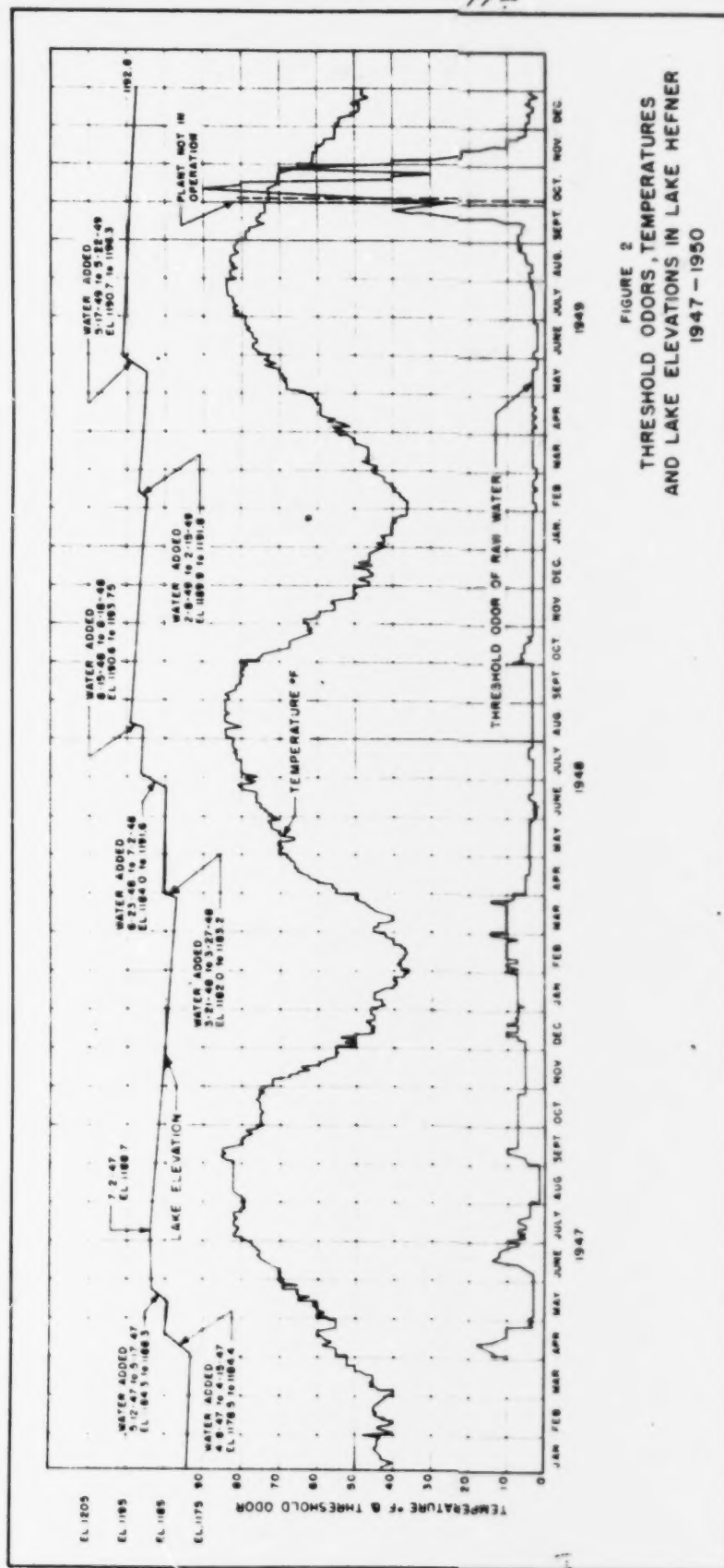
Impoundment in Hefner Reservoir was begun in July, 1943. From this date on, water was diverted to the lake during rainy seasons. Water diverted to the reservoir is carefully selected with the aid of chemical analyses of water taken upstream, in order that the softest water can be

impounded. In so far as possible, the Corps of Engineers cooperates in this undertaking by closing the gates at Canton Reservoir on request so that only the runoff from that portion of the drainage basin below Canton Reservoir is impounded. Variations in total hardness and total chlorides in the water of the North Canadian River for the period February, 1949 to March, 1950, are shown in Figure 1. In general, periods of high water occur in May, June or October. By impounding water during these flood periods it has been possible to maintain softer water in Lake Hefner than is generally available in the river (Figure 1 and Table 3).

By the end of 1944, the reservoir had been filled to elevation 1180.5 and contained some 37,000 acre feet of water. Water levels did not vary greatly during 1945-46 and 47, the water level being 1182.1 feet, 1180.0 feet and 1183.2 feet at the end of each of these years. Considerable water was added in June, 1948, bringing the water elevation up to 1191.1 feet and the storage to about 57,000 acre feet. During August, the water level was raised to 1193.8 but it dropped to 1189.8 by the end of this year. Reservoir elevations during 1947-48 and 49 are plotted in Figure 2. A peak elevation of 1196.3 was attained on May 24, 1949, but after June 19 there was a gradual lowering during the remainder of the year. As indicated in Figure 2, the greatest taste and odor problem occurred during a receding lake level.

The Lake Hefner water treatment plant was put into operation on December 16, 1946. Two weeks later a fishy, swampy, woody-like odor began to appear in the heated water which grew worse as the season advanced.





The appearance of this odor was unexpected because the reservoir had been carefully prepared, all trees and brush having been grubbed out and grass and trash burned. Further, plankton samples taken earlier in the season had indicated rather scant algal growths with counts ranging around 200 standard areal units per ml. The lake was treated with copper sulphate in January and February, treatments being at the rate of 0.12 and 0.15 ppm. These treatments seemed to have no effect and as the water temperature dropped from 50° to 43° F., it was decided that algae were probably not responsible. Efforts were then directed toward removal of the odor in the treatment plant. Ammonia, chlorine, chlorine dioxide and softening were tried with varying degrees of success. The threshold odor reached a peak of 18 in April and then decreased sharply on the addition of new water to the reservoir. The threshold odor increased again to 14 for a short period in June but during the remainder of the year and until February, 1948, it varied between 5 and 10. With the addition of water in early April, 1948, threshold odors dropped below 5 and remained low until August, 1949, when they increased greatly reaching a peak of 90 in October. Cost of chemical treatment, the amount of carbon and chlorine used and other pertinent data on the water of Lake Hefner during this period are summarized in Table 3. Threshold odors in raw and tap water and water temperatures for the period January, 1947, through December, 1949, are shown graphically in Figure 2.

Plankton Population -

In February, 1948, the services of Mr. Ivan Ophel of the Plant Sciences Department of the University of Oklahoma were obtained (through payment of funds to the University by the City) to make an extended study

TABLE 3

LAKE HEPPIE

Water Quality and Treatment

Date	Turbidity of Raw Water			Total Alkalinity of Raw Water			Threshold Odor of Raw Water			Total Hardness of Raw Water		
	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.
Dec. 46	10	10	10	161	165	160				197	205	193
Jan. 47	10	10	10	161	164	160				194	203	182
Feb. 47	10	10	10	162	165	161				194	205	186
Mar. 47	10	20	10	164	168	160				197	210	186
Apr. 47	43	130	10	154	170	145	9	18	3	189	212	176
May 47	22	40	20	144	150	138	3	3	3	185	200	162
June 47	21	40	20	140	146	134	7.6	14	3	173	191	162
July 47	120	120	120	146.6	156	138	5.1	7	4	189	204	159
Aug. 47	20	20	20	151	158	144	4	5	4	189	200	177
Sept 47	20	20	20	148	150	145	7	10	4	171	198	161
Oct. 47	20	20	20	149			6	7	5	188	190	170
Nov. 47	20	20	20	151	154	150	5	5	5	185	204	156
Dec. 47	20	20	20	153	154	150	7	10	5	185	192	165
Jan. 48	20	20	20	152	153	150	7	10	2	181	191	164
Feb. 48	20	20	20	153	155	151	10	14	7	186	202	173
Mar. 48	20	20	20	149	155	144	10	14	5	186	202	151
Apr. 48	20	20	20	148	150	147	4	5	4	180	188	170
May 48	20	20	20	150	152	147	4	4	3	185	192	176
June 48	20	20	20	146	154	130	3	4	1.5	192	209	169
July 48	20	20	20	136	143	132	3.5	4	3	180	190	164
Aug. 48	20	20	20	142	147	137	3	3	3	176	192	162
Sept 48	10	10	10	148	153	146	3	3	3	179	185	174
Oct. 48	10	10	10	151	154	150	4	7	3	193	197	176
Nov. 48	10	10	10	151	152	146				188	192	184
Dec. 48	10	10	10	153	156	150	3	4	3	190	196	184
Jan. 49	10	10	10	151	154	145	3	3	3	189	194	183
Feb. 49	11	12	10	147	154	140	3	3	2	182	196	178
Mar. 49	12	12	12	146	148	142	3	3	2	181	186	176
Apr. 49	12	12	12	147	149	145	3	3	2	183	188	178
May 49	17	65	12	145	149	137	3	3	2	179	188	164
June 49	19	48	10	136	139	135	2	3	2	171	177	163
July 49	10	10	10	137	139	135	3	4	3	172	178	168
Aug. 49	10	10	10	139	140	137	5	7	3	170	179	164
Sept 49	10	10	10	140	140	138	13	40	5	173	187	167
Oct. 49	10	10	10	140	140	139	49	90	30	178	188	174
Nov. 49	10	10	10	140	142	140	18	40	5	175	180	168
Dec. 49	10	10	10	141	143	140	4	5	3	175	180	168
Jan. 50	10	10	10	142	144	140	3	4	2	176	183	170
Feb. 50	10	10	10	144	145	142	2	2	2	180	184	175

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TABLE 3 (Cont'd)

LAKE HEPNER

Water Quality and Treatment

Date	Cost Chem. per M.G.	Lbs. Cl./ M.G.	Lbs. C/ M.G.	Temperature			Dissolved Oxygen P.P.M.			pH of Raw Water		
				Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.
Dec. 46	8.29	37.3										
Jan. 47	9.81	22.0	44.8	43	48	40				8.2	8.4	8.1
Feb. 47	12.67	30.5	59.6	43	45	40				8.2	8.5	8.0
Mar. 47	14.34	17.7	68.2	46	52	40				8.25	8.6	8.1
Apr. 47	13.68	25.2	67.8	57	62	55				8.2	8.5	8.4
May 47	8.78	25.1		66.5	70	60				8.3	8.5	8.0
June 47	7.77	21.4	8	75	70	82				8.35	8.7	8.1
July 47	10.33	21.3		81.2	82	79				8.2	8.6	7.7
Aug. 47	11.43	21.0		82	82	82				8.2	8.3	7.8
Sept 47	9.51	19.6		79	85	74				8.1	8.6	8.0
Oct. 47	9.32	19.6		74	76	69				8.6	8.7	8.6
Nov. 47	9.37	16.0		57	68	50				8.6	8.7	8.5
Dec. 47	13.42	10.25	60.2	47	54	44				8.5	8.6	8.4
Jan. 48	16.84	10.0	94.6	40	44	36				8.3	8.4	8.0
Feb. 48	18.26	10.1	127	39	45	36				8.2	8.2	8.0
Mar. 48	19.14	13.6	130.5	47	55	40				8.2	8.4	8.0
Apr. 48	11.30	21.6	10.9	63	68	55				8.4	8.5	8.0
May 48	10.93	23.3	20.4	70	73	66				8.5	8.6	8.3
June 48	11.23	23.4	17.6	76	81	72				8.5	8.6	8.3
July 48	12.27	26.4	28.3	81	82	79				8.3	8.4	7.8
Aug. 48	12.83	26.1	27.8	83	84	80				8.2	8.3	8.1
Sept 48	11.87	23.8	15.6	81	84	75				8.2	8.4	8.1
Oct. 48	10.85	20.3	16.8	66	75	61				8.4	8.5	8.3
Nov. 48	9.29	16.5		54	63	46				8.5	8.6	8.4
Dec. 48	12.66	12.55		46	50	42				8.5	8.6	8.3
Jan. 49	10.85	11.43		38	43	36				8.5	8.6	8.3
Feb. 49	10.07	15.1		40	45	36				8.5	8.6	8.3
Mar. 49	11.08	24.5		48	55	44				8.5	8.6	8.2
Apr. 49	12.25	23.8		57	62	51				8.5	8.6	8.3
May 49	10.09	26.5		71	75	63	6.2	6.5	5.5	8.5	8.7	8.1
June 49	9.27	28.6		78	81	76	5.4	6.3	3.9	8.4	8.5	8.2
July 49	9.69			82	84	81	4.8	7.1	2.3	8.5	8.6	8.4
Aug. 49	14.64	30.3	70.8	82	83	79	6.2	6.9	3.5	8.5	8.6	8.3
Sept 49	46.50	77.8	425.	77	79	74	7.3	8.1	6.0	8.5	8.5	8.3
Oct. 49	52.36	96.5	496.	68	73	61	7.8	8.9	6.1	8.5	8.5	8.4
Nov. 49	27.00	38.6	186.	59	62	55	9.5	9.1	10.0			
Dec. 49	14.92	27.05	31.5	50	55	45	10.1	11.0	9.0	8.5	8.5	8.4
Jan. 50	12.43	12.85	10.7	45	51	41	10.6	10.6	9.6	8.5	8.5	8.3
Feb. 50	12.30	10.76		45	49	41	10.0	11.0	8.6	8.5	8.6	8.3

of the phytoplankton in Lakes Hefner and Overholser. He found that in spite of the fact that turbidity is much higher in Overholser than in Hefner (Tables 1 and 3) the phytoplankton population has been consistently higher in the former. On the basis of 400 samples taken over a period of 2 years, the mean annual standing crop of phytoplankton was 135,800 areal standard units per liter in Lake Overholser, while, in Hefner, as indicated by the same number of samples, it was 122,500 standard areal units per liter. The various species of algae found in the two reservoirs are listed in Table 4. The plankton population of Lake Overholser was found to contain relatively more diatoms, while Hefner had more green algae, particularly in the summer. In Overholser, the population was more uniform throughout the year. In Hefner Reservoir, the population was highest in summer and lowest in winter. The highest population encountered in Lake Hefner was found on July 9, 1949, while one of the lowest was found on January 19, 1950. The organisms found on these dates and the areal standard units represented by each species are shown in Tables 5 and 6.

The dominant species of algae found throughout the study are:

- Sphaerocystis schroeteri*
- Microcystis flos-aquae*
- Pediastrum simplex*
- Pediastrum duplex*
- Staurostrum chaetoceros*
- Coelastrum microporum*
- Phacetus lenticularis*
- Ankistrodesmus falcatus*
- Closterium aciculare*
- Melosira granulata*
- Cyclotella* spp.
- Phacus pyrum*
- Merismopedia glauca*

TABLE 4

A List of Algae Found in Lakes Overholser and Hefner

<i>Actinastrum hantzschii</i>	<i>Microactinium pusillum</i>
<i>Aphanizomenon flos-aquae</i>	<i>Microcystis aeruginosa</i>
<i>Ankistrodesmus falcatus</i>	<i>Navicula dicephala</i>
<i>Ankistrodesmus acicularis</i>	<i>Nitzschia linearis</i>
<i>Ankistrodesmus mirabilis</i>	<i>Nitzschia palea</i>
<i>Anabaena spiroides tenuum</i>	<i>Nitzschia tryblionella</i>
<i>Aphanocapsa delicatissima</i>	<i>Oocystis leongei</i>
<i>Asterococcus superbus</i>	<i>Oocystis lacustris</i>
<i>Botrydiopsis</i> sp.	<i>Oocystis parva</i>
<i>Botryococcus braunii</i>	<i>Oocystis pusilla</i>
<i>Ceratium hirundinella</i>	<i>Pandorina morum</i>
<i>Chlamydomonas</i> sup.	<i>Pascheriella tetras</i>
<i>Chlorococcum infusionum</i>	<i>Pediastrum simplex</i>
<i>Cladophora</i> sp.	<i>Pediastrum duplex</i>
<i>Closterium aciculare</i>	<i>Peridinium tabulatum</i>
<i>Closterium cornu</i>	<i>Phacotus lenticularis</i>
<i>Coelastrum microporum</i>	<i>Phacus pyrum</i>
<i>Coelastrum sphaericum</i>	<i>Phacus longicauda</i>
<i>Coelosphaerium naegelianum</i>	<i>Phacus pleuronectes</i>
<i>Cosmarium</i> sp.	<i>Planktosphaeria gelatinosa</i>
<i>Crucigenia fenestrata</i>	<i>Scenedesmus acuminatus</i>
<i>Crucigenia quadrata</i>	<i>Scenedesmus arcuatus</i>
<i>Crucigenia rectangularis</i>	<i>Scenedesmus bijuga</i>
<i>Cryptomonas</i> sp.	<i>Scenedesmus dimorphus</i>
<i>Cyclotella kuetzingiana</i>	<i>Scenedesmus obliquus</i>
<i>Cyclotella meneghiniana</i>	<i>Scenedesmus quadricauda</i>
<i>Dictyosphaerium pulchellum</i>	<i>Schroederia setigera</i>
<i>Dioloneis elliptica</i>	<i>Sphaerocystis schroeteri</i>
<i>Elakatothrix viridis</i>	<i>Staurostrum chaetoceros</i>
<i>Euglena tripteris</i>	<i>Staurostrum tetracerum</i>
<i>Euglena oxyuris</i>	<i>Stephanodiscus astraea</i>
<i>Franceia droescheri</i>	<i>Surirella spiralis</i>
<i>Glenodinium</i> sp.	<i>Synedra acus</i>
<i>Golenkinia radiata</i>	<i>Synedra berolinensis</i>
<i>Gyrosigma scalproides</i>	<i>Synedra ulna</i>
<i>Kirchneriella contorta</i>	<i>Synura uvella</i>
<i>Kirchneriella elongata</i>	<i>Tetraedron constrictum</i>
<i>Lagerheimia citrififormis</i>	<i>Tetraedron trigonum</i>
<i>Lagerheimia longiseta</i>	<i>Tetrallantos lagerheimii</i>
<i>Lagerheimia quadriseta</i>	<i>Tetrastrum elegans</i>
<i>Lepocinclis</i> sp.	<i>Tetrastrum staurogeniaeforme</i>
<i>Lynghya limnetica</i>	<i>Trachelomonas hispida</i>
<i>Malcomonas</i> sp.	<i>Trachelomonas volvocina</i>
<i>Melosira distans</i>	<i>Trochiscia reticularis</i>
<i>Melosira granulata</i>	<i>Uroglenopsis americana</i>
<i>Merismopedia glauca</i>	<i>Westella botryoides</i>
	<i>Westella linearis</i>

The average monthly plankton populations in each of the reservoirs expressed as areal standard units per ml are shown in Table 7. It will be noted that during 1948, the phytoplankton population was larger in Lake Hefner during July, October and November and during the latter half of 1949. Further, during September, October and November, 1949, when threshold odors were so high phytoplankton populations ranged from 170 to 152 areal standard units and were much lower than they were during June, July and August, when the threshold odor remained under 5, Figure 2. Experience has shown that with most species of algae, tastes and odors are not perceptible until their concentration is between 500 to 1000 areal standard units per ml. In view of the fact that the peak population found in Hefner was 586 areal units, that average populations were lower than those in Lake Overholser which did not have taste and odor problems and that high threshold odors did not occur at times of high phytoplankton populations it is concluded that the tastes and odors in Lake Hefner have probably not been due to algae.

When examined in March, 1950, Lake Hefner had a barren appearance. The water was clear, the shore line clean and of bare clay, there were no rich bays or extensive shoal areas and in general it did not have the appearance of a lake which would present algal problems. A mineral analysis of the water by Mr. Walling of the U.S. Geological Survey, Table 8, indicated that phosphate was absent in the lake water. The minimum amount of phosphates considered to be essential for extensive plankton growth is 0.02 ppm.

TABLE 5
LARGE SUMMER PLANKTON POPULATION
LAKE HENNER

Location No. 1 Date July 9, 1949 Taken by I. L. Ophel
Examined by I. L. Ophel Date July 9, 1949 Concentration 500 to 5
Factor 2

Genus and Species	Areal Standard Units (Count)					Count
	1	2	3	4	5	
<u>Chlorophyceae</u>						
Pediastrum simplex	25	22	6	10	12	150
Coelastrum	3	1	6	2		24
Ankistrodesmus	1				1	4
Sphaerocystis	1				3	8
Oocystis			1		1	4
Phacotus					1	2
<u>Chrysophyceae</u>						
Ceratium	6				5	22
<u>Bacillariophyceae</u>						
Melosira	6		7			26
<u>Diatophyceae</u>						
Aphanizomenon	2	12	6	8	4	64
Microcystis aeruginosa	18	24	25	20	30	234
Microcystis marginata		4	9	6	5	48
TOTAL ORGANISMS						586
Amorphous	12	10	12	15	18	134

TABLE 6
SMALL WINTER PLANKTON POPULATION

LAKE HETTER

Location No. 3 Date 19 January 1950 Taken by I. L. Cphel
Examined by I. L. Cphel Date 19 January 1950 Concentration 500 to 5
Factor 2

Genus and Species	Areal Standard Units (Count)					
	1	2	3	4	5	Count
<u>Chlorophyceae</u>						
Sphaerocystis	2		1			6
Closterium	3					6
Staurastrum	1		3		1	10
Ankistrodesmus	1	1				4
Coelastrum			1		1	4
Oocystis			1		2	6
Podiastrum						
TOTAL ORGANISMS						36
Amorphous	30	20	25	18	20	226

TABLE 7

Average Monthly Population of Plankton in Lakes Overholser
and Hefner Expressed in Areal Standard Units per ml.

<u>Date</u>	<u>Overholser</u>	<u>Hefner</u>
1948		
Feb.	281	114
March	222	33
April	151	38
May	246	94
June	231	121
July	141	220
Aug.	155	133
Sept.	220	174
Oct.	162	283
Nov.	106	185
Dec.	52	44
1949		
Jan.	58	12
Feb.	120	27
March	172	42
April	126	18
May	135	33
June	93	145
July	141	450
Aug.	146	248
Sept.	85	170
Oct.	76	167
Nov.	91	152
Dec.	31	51
1950		
Jan.	43	30

TABLE 8

Analyses by U. S. Geological Survey Laboratory, Stillwater, Okla.
Unpublished records, subject to revision

	Sample 1		Sample 2		Sample 3	
	P.P.M.	E.P.M.	P.P.M.	M.P.M.	P.P.M.	M.P.M.
Iron (Fe)	0.00		0.00		0.00	
Silica (SiO ₂)	3.4		2.8		12	
Phosphate (PO ₄)	.00		.01		.00	
Manganese (Mn)	.00		.00		.00	
Calcium (Ca)	49	2.445	18	0.898	87	4.34
Magnesium (Mg)	17	1.398	10	.822	33	2.71
Sodium (Na)	50	2.174	49	2.131	123	5.33
Potassium (K)	10	.256	8.7	.222		
Bicarbonate (HCO ₃)	181	2.966	1/53	.879	236	3.87
Sulfate (SO ₄)	67	1.395	70	1.457	185	3.85
Chloride (Cl)	57	1.608	60	1.692	164	4.62
Fluoride (F)	.3	.016	.3	.016	.7	.04
Nitrate (NO ₃)	.0	.000	.5	.008	.0	.00
Total dissolved solids	346		245		740	
Total hardness as CaCO ₃	192		86		352	
Non-carbonate hardness	44		42		159	
Ignition loss	33		19		66	
Specific conductance at 25° C. (micromhos)	583		440		1190	
pH	8.4		9.8		7.9	
Per cent sodium	35		52		43	
Color (units)	15		5		10	

1/ Includes equivalent of 19 parts per million of carbonate (CO₃).

Oklahoma City Lake Hefner Municipal Water Supply

Sample 1 - Raw water collected by I. W. Walling from faucet in laboratory of treatment plant, 3:10 p.m., March 15, 1950. Temperature of water - 54° F.

Sample 2 - Finished water collected by I. W. Walling from faucet in laboratory of treatment plant, 3:12 p.m., March 15, 1950. Temperature of water - 48° F.

Sample 3 - Canton Reservoir on North Canadian River at Canton, Okla. Sample collected 100 feet above Dam outlet by H. W. Poston, 3:40 p.m., March 17, 1950. Gage Height-1603; temperature of water - 48° F.

Ecology and Effects of Actinomycetales -

In searching for organisms other than algae which might be responsible for tastes and odors, Mr. Ophel isolated and cultured an actinomycete. When grown on a nutrient agar these organisms produced an odor of musty straw which was the same as that noted in the water.

It has been known for some time that Actinomycetes were present in lakes. Umbreit and McCoy (10) reported that up to 50% of the microorganisms found in Wisconsin lake waters during the summer months were Actinomycetales of the genus *Micromonospora*. They were also present in large numbers in bottom deposits. In winter, 12,500 *Micromonospora* were found per ml. of wet mud from a bay of Lake Mendota that was ice covered. Just after the ice breakup, the population was found to be 100,000 per ml. of wet mud, and in June two samples showed 120,000 and 250,000 *Micromonospora* per ml. of wet mud. At depths of 12 to 15 meters, they comprised 45% of the total organisms found while at 24 to 30 meters they comprised up to 70% of the total population. It was found that the population of the beach approaches that of the soil. Here the fungi and soil actinomycetes make their appearance.

As early as 1891, it was suspected that organisms occurring in the soil were the cause of the "earthy odor" of the soil. In 1895, a fungus-like organism (now known as *Streptomyces albus*) which produces an earthy smelling substance during its life activity was isolated from the soil. Subsequently, many related forms have been found that produce the same type of odor. Of thirty strains of actinomycetes isolated from soil by Waksman and Curtis in 1916 (20), twenty-four of them were found to produce odors of varying intensities. Members of the order Actinomycetales are

widely distributed in the soil and the mud of lakes. Fousek (15) found them to comprise 20 to 30% of the organisms in loam soils and Conn (14) found that they accounted for as much as 40% of the soil microbiota. Jensen (23) reported that cultures of Actinomyces griseus possess a very strong "soil" odor and some strains produce a remarkably pungent smell of rusty straw.

At a meeting of the Public Works Congress in London in 1931, it was reported that Actinomycetes had been found growing in water pipes and that they were probably responsible for tastes and odors in the water. Since then there have been several instances in the United States and Russia where actinomycetes have been credited with producing tastes and odors. In 1942, Egorova and Isatchenko reported the development of an earthy smell and taste in a Russian reservoir as a result of the life activities of actinomycetes. The microorganisms were found chiefly in the upper 20 centimeters of the bottom silt.

Actinomycetales may utilize a variety of substrates for growth. Russell (17) lists carbohydrates and proteins as the chief sources of food and energy material but some decompose cellulose, soil humus, lignin and keratin. The highest numbers occur over a pH range of 6.8 to 8.0. Many species grow best at a temperature of 30° C. with a minimum of about 15° C. and a maximum of about 50° C. However, Micromonospora grows at much lower temperatures as it was found in mud under ice by Umbreit and McCoy (10). These workers believe that these forms feed largely on cellulose and other dead plant materials.

Dr. J.K.G. Silvey, of North Texas State College, has been among the first in this country to point out the role of Actinomycetes in the production of tastes and odors in water supplies. He has studied Actinomycetes in reservoirs for a number of years and he believes that they are responsible primarily for all taste and odor problems in the southwest. While investigating algal cycles in four Texas reservoirs (Silvey, 1949), two of which were rich in phytoplankton and two of which were rather barren, he found that one of the barren reservoirs developed offensive tastes and odors as did one of those having high plankton populations. Odors did not develop in the other rich lake even though the algal populations in the two lakes were very similar. Investigations resulted in the isolation of cultures of Streptomyces from those waters having odors. When grown in pure culture these organisms produced a concentration of tastes and odors like that found in the reservoirs. Dr. Silvey has extracted taste and odor producing substances from these cultures. In conversations with him, he pointed out the following:

"The Streptomyces found in southwestern reservoirs are especially responsive to changes in temperature. The minimum temperature at which spores will germinate to produce vegetative growth is 15° C. At this temperature few byproducts are produced. At 17° C. the byproducts may be extracted either from water or from a culture medium although the total concentration of chemicals will be minimal. As the temperature increases activity is enhanced and the maximum temperature for growth stimulation is not exceeded in natural waters. Light is unimportant for the growth of these organisms as no differences were observed in the byproducts produced in the light or the dark. It is believed these actinomycetes grow best in 6 inches to a foot of water and that they grow very little at depths of 40 feet or more. Actinomycetes grow on a variety of aquatic plants, cattails, willows, bullrushes, etc., and when these are absent they may grow on algae or dead plankton. They grow best under conditions of high alkalinity, temperature and mineral content. They do not grow well on acid sandy soils and in waters having such bottoms they usually do not create problems.

"The concentration of Streptomyces is directly proportional to certain types of available organic matter. Polysaccharides, proteins, peptids, amino acids and other complex organic compounds serve as nutrients. The amount and kind of byproducts produced by actinomycetes is dependent upon the source of their nutriment, the temperature and the alkalinity of the water. Major byproducts of Streptomyces in normal cultures are unsaturated fatty acids and amines. Amines appear to be of at least two types, isoamylamine and isobutylamine. A variety of unsaturated fatty acids are also probably found. Odors are believed to be due to the simple and complex amines. A concentration of 0.2 ppm is necessary to produce noticeable tastes and odors. As the concentration increases, odors and tastes become more apparent and may become manurial during the maximum heat of summer.

"If prechlorination is used in water supplies containing such substances the amines will unite with the chlorine to form various types of chlorinated amines that exhibit odors described as muddy-fishy, earthy-marshy, earthy-manurial, woody-musty, rotten stump or woody-fishy. Chlorine dioxide is effective in eradicating odors provided chlorine is not used in conjunction with it. Chlorinated amines require five times as much ClO_2 for oxidation as do the amines alone. Other substances may be effective for oxidizing the odor producing products. It is thought that fluorine trioxide may be effective but ozone and bromine have been tried without success.

"There is no known practical chemical control for actinomycetes in natural waters. Copper, chlorine and arsenicals have been tried with little success. Sodium chlorite in concentrations of 10 ppm will eradicate them but it is very expensive to use.

"Spores of actinomycetes are so small that they pass through common bacterial filters such as Seitz or Berkefeld. The spores will also pass through water purification plants and be carried to the mains where they become attached and grow if temperatures are favorable. The water must reach 17°C . (63°F .) before significant odors are produced. Thus, deep distribution systems that remain below 17°C . are recommended.

"When actinomycetes are established on mineral deposits in mains they can be controlled by adding approximately 8 ppm of chlorine dioxide. This concentration must be added to the total system every 5 days because the spores are not readily killed and the spore incubation period is about 7 days."

Because offensive tastes and odors have developed in Hefner Reservoir and not in Overholser and they seem to be not due to algae, it is believed that they are probably connected with impoundment and the

flooding of former dry land areas. The officials of the Oklahoma City Water Department are, therefore, apprehensive of the effect Canton Reservoir may have in the future on the supplies of both Hefner and Overholser. Because areas in Canton may be periodically flooded and dewatered, they fear a continuous production of tastes and odors which may be carried down stream to Oklahoma City at times when they wish to impound water. It was with this possibility in mind that Canton Reservoir was examined.

Canton Reservoir, Present Condition and Ecology -

Canton Reservoir was constructed primarily for flood control, irrigation, water supply and recreation. Construction began in December, 1940, but was suspended in 1942 because of the war. Work was resumed in March, 1946, and the reservoir was completed in 1949. Because the principal use of the reservoir is for flood control, water levels are kept low in order to maintain a maximum storage capacity for flood waters. The top of the permanent or conservation pool has been set at 1596.5 feet at which elevation the reservoir has an area of 3300 acres and a storage capacity of 23,000 acre feet. The flood control act of July 24, 1946 authorized the provision of 69,000 acre feet of the initial storage in the reservoir for irrigation purposes. The top of the initial irrigation pool is at elevation 1610 at which level the lake has an area of 6700 acres and contains 92,000 acre feet of water. The top of the flood control pool is at elevation 1638 at which elevation the lake has an area of 15,500 acres and a storage capacity of 390,000 acre feet of water.

Maximum peak flows on the North Canadian River at Canton of 80,000 to 90,000 cfs were recorded on October 13, 1923. Severe floods have occurred

in June, 1915; June, 1916; May, 1918; May, June and October, 1923; May, 1935; October, 1941; and October, 1946. The drainage area above Canton is 11,640 square miles. The average annual rainfall in the area varies from 26 inches at the damsite to about 16 inches in the upper end of the valley in New Mexico. When flood flows occur, large areas of the reservoir will be flooded and may remain under water for some time as the outflow from the dam is regulated. The bank full capacity of the stream below Canton Reservoir is considered to be 4,000 cfs.

The gates of Canton Dam were closed in April, 1948. During July there was a peak inflow of about 1200 cfs and the reservoir rose to elevation 1597 and was held fairly constant until January of 1949 when the reservoir was raised to elevation 1599. During February, the pool was raised to 1605 as a flood surcharge for the removal of driftwood. In May, an inflow of 15,000 cfs for a short period raised the pool to elevation 1614 which is the highest stage the reservoir has reached. In June the pool was dropped to 1605 and was held fairly constant until December when it was lowered to 1603. It is now being held constant at that level as it creates a pool which is more suitable for fishing, recreation, and overall operation.

Beaches are now being formed along much of the shoreline in the lower portion of the reservoir. On the south side of the reservoir, near the dam, the soil is largely red clay and the shore drops off quite rapidly. There are few shallow flats and aquatic vegetation is not abundant. The shoreline is actively eroding and it is not likely that much aquatic vegetation will become established in the next few years. Since there are few coves and

protected areas, wave action, turbidity and fluctuations in water levels will tend to keep the shoreline clean.

In the upper portion of the reservoir there are extensive flat areas between elevations 1603 and 1610. Much silt has already been deposited in this area and extensive willow growths are already established. It is to be expected that the deposition of silt in this area will create extensive rich flats which will become covered with willows and other vegetation. At certain elevations these areas will have a shallow covering of water which should be productive of some forms of life.

In the upper half of the reservoir there is a very extensive area between the 1610 and 1635 contours. The lower portion of this area is quite flat and has numerous depressions or swales which will hold water during certain times of the year if the reservoir elevation is raised to about 1615. Dense vegetation will probably develop in these swales.

It is believed that during the next few years extensive silt flats will develop in the upper end of the irrigation pool. Willows will probably become established on these flats and will migrate to elevations of 1603 or lower due to drawdowns. Once established, many of these willows will live even though pool levels are raised to 1610. Such willow covered areas are not desirable from the standpoint of fish and waterfowl because bottom organisms are usually scarce in such areas and aquatic vegetation which provides food for waterfowl is largely eliminated. If the water remains alkaline, however, the large amount of organic material collecting in the area may provide suitable conditions for actinomycetes which can grow in the absence of sunlight.

The north side of the reservoir has a more gradual slope. The soil is sandy and there are many old sand dune hills and ridges which produce many protected bays and coves. Although the soil is now sandy and fairly barren in this area, the deposition of silt and the collection of organic matter probably will make these coves richer after a number of years. When the water level is at elevations above 1603, these protected areas should support extensive plant growths and large algal populations if the coppice does not become thick enough to shade them out.

Water from Canton Reservoir is used to supply the Corps of Engineers office and a recreational building. To date no offensive odors have been noted in the water. Wind action is pronounced in the reservoirs and many areas are made turbid. However, during the summer, there are quiet periods during which the water becomes fairly clear and stratification develops. There will probably be times when phytoplankton becomes abundant. Knowledge of the ecological requirements of the actinomycetes is so scant that it is impossible to predict whether or not there will be extensive growths of these organisms. Extensive areas which are covered with vegetation will be flooded at times and it is possible that offensive odors will develop. During floods the time of flow from Canton Reservoir to Oklahoma City is fairly short and as water is impounded during periods of high flow it may be possible for odors produced in Canton Reservoir to reach Oklahoma City. Much more study is needed on the occurrence, life history and ecology of taste and odor producing organisms before this question can be answered.

Summary and Conclusions

The control of tastes and odors is an outstanding problem of water works operators. Offensive tastes and odors in public water supplies often result in public health problems as they cause many people to turn to unsafe water supplies. The odor and taste problem is not a local one with Oklahoma City as earthy, musty or woody odors have occurred in the surface water supplies of several other Oklahoma cities. They have also occurred at Dallas, Texas, and in other cities of the Southwest. No really adequate means for the control of these odors are available and the method in most common use is very expensive as it requires large quantities of chemicals and often necessitates the addition of extensive plant facilities.

During the period of high threshold odors in the Oklahoma City water supply chemical costs for water treatment increased several fold. During the months of September, October and November the average cost of chemicals used for each million gallons of water treated was \$9.40 in 1947; \$10.67 in 1948; and \$41.95 in 1949. Thus, the tastes and odors which occurred in the fall months of 1949 increased the cost of water treatment \$32.55 and \$31.28, respectively, per million gallons over those required during the same period in 1947 and 1948 when no special problem existed. If water from Lake Hefner had been utilized during these three months in 1949, as it had been used during the same period in 1947 and 1948, the cost of the additional chemicals used to control odors would have been over \$30,000.00. Also, a recurrence of the problem will, unless some other method of control is found, necessitate extensive additions to the water plant which are estimated to cost \$2,000,000. This is made necessary because at normal

application rates some of the carbon passes through the filters and a smaller application rate is required.

Studies made to date suggest that the offensive tastes and odors in the Lake Hefner waters are not produced by mass growths of algae as the algal population is generally low, never reaching a level which is considered sufficient to create a problem. Further, tastes and odors reached a peak at a time when the phytoplankton population was much lower than it was during the summer months. Also, Lake Overholser which has had a larger average plankton population has not had taste and odor problems.

Because odors similar to those noted in Lake Hefner have been produced by an actinomycete isolated from the lake and grown in culture media, it would appear that actinomycetes may be responsible for the tastes and odors in Lake Hefner. It is probable that flooding of dry land areas, fluctuations of water level and intermittent covering of marginal vegetation are conducive to the growth of actinomycetes in reservoirs. It may be that under conditions of intermittent flooding soil actinomycetes not normal to the deeper areas of natural lakes survive to create problems. Dense vegetative growths in marginal areas and the accumulation of organic debris along shorelines favor their growth. It is probable that they may persist in reservoirs having fluctuating water levels even though they are absent in natural lakes. The fact that fungi and Streptomyces characteristic of the soil appear in the shore zones of natural lakes while Micromonospora is the dominant form of the Actinomycetales in deeper waters suggests that the former group may become a problem in many impoundments in the warmer areas where temperature conditions are favorable.

Micromonospora grows at cool temperatures and has been found under an ice cover but, according to Dr. Silvey, Streptomyces require temperatures of 15° C. and higher. If this temperature holds for the group, all tastes and odors in Lake Hefner are not due to Streptomyces as offensive odors were encountered also during the first three months of 1947. Some other genera or some other organism must be involved.

The addition of new water to Lake Hefner caused a sharp reduction in tastes and odors. The raising of the lake level and the flooding of new areas did not cause tastes and odors within a month. Severe tastes and odors occurred generally during periods of recession and at considerable intervals after rises in the lake level. If tastes and odors are due to actinomycetes growing on organic material in the shallow fluctuating zone the effects must be delayed or it takes the taste and odor producing substances a long time to move from the shallows to the water intake. It is desirable to determine just where the odors are produced and when and how they reach the water intake.

Because water had been impounded for some three years in Lake Hefner before being used and most of the water selected for impoundment in the reservoir came from the watershed below Canton Dam, tastes and odors arising in this reservoir in the past cannot be ascribed to the creation of Canton Reservoir.

When the water level of Canton Reservoir is raised to elevations between 1605 and 1615, protected shallow water covers will be formed along the north side which will probably be very productive of plant life. Extensive silt flats will develop at the upper end of the irrigation pool

which can be expected to become covered with willows. Organic material will collect in these areas and if the total alkalinity remains high, taste and odor producing organisms may develop.

At this time, however, it cannot be stated definitely that tastes and odors actually will develop which will affect the Oklahoma City water supply.

Much more needs to be known of the occurrence and ecological requirements of taste and odor producing organisms before this can be predicted. Further, their nutritive requirements, life history and byproducts must be known before they can be effectively controlled by manipulation of the environment in the reservoirs, by chemical means or their byproducts can be made inoffensive by chemical means.

In view of the cost of additional plant facilities and chemicals needed for the control of tastes and odors in Lake Hefner water, it is evident that there is justification for the Oklahoma City Water Department carrying out extensive investigations for the determination of the cause and control of this problem. It would seem wise to reexamine the water during periods of taste and odor production for specific kinds of algae such as Synura and Synedra which even in comparatively small concentrations are known to cause perceptible tastes and odors. Intensive sampling and other investigations should be carried out to determine the organism or organisms responsible for the tastes and odors, their location in the lake and the manner in which the offending byproducts spread throughout the reservoir. It may be that there is a considerable period between the production of the offending products and their arrival at the intake tower. After the offending

organisms are determined detailed investigations should be made of their life histories, nutritive requirements and ecology. This knowledge is essential before adequate biological or chemical control measures or various combinations of them can be devised. Further, the nature of the offending byproducts should be determined in order that they may be neutralized or more effectively dealt with in the water plant.

While these studies are being carried out, it is recommended that vegetation in and bordering the reservoir be kept at a minimum. Drift should be burned as soon as it is dry enough in the spring. Flats which are to be covered when the water level is raised usually in May should be burned and kept as bare as possible until they are inundated. Marginal and aquatic vegetation may be controlled.

Methods in current use for the control of tastes and odors require large amounts of chlorine and activated carbon. Large amounts of chlorine are taken up by the carbon and they tend to neutralize each other. Dr. Silvey has developed a method for the use of chlorine dioxide for the control of these tastes and odors. He states chlorine should not be used when chlorine dioxide is to be applied. Chlorine might be omitted and chlorine dioxide applied to the filtered water which has been treated with activated carbon. It is suggested that Dr. Silvey be contacted and his procedures given a trial.

Because the tastes and odors in question are adsorbed on carbon, it is suggested that a carbon filter similar to those now being used by the Environmental Health Center in taste and odor studies be utilized for the collection and concentration of these materials in Lake Hefner water. The concentrate can then be analyzed and the chemical nature of the offending material may be determined. Plans and procedures for this work are available at the Environmental Health Center.

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